CLAIMS:

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1. A machine for abrading or polishing a workpiece, the machine comprising:

a holding surface for holding said workpiece;

a head member arranged along a rotation axis to rotate about the rotation axis;

a working member having a surface for abrading or polishing said workpiece arranged on said head member on said rotation axis for rotation about said rotation axis with said head member;

first driving means for driving said head member and said working member mounted thereon to rotate about said rotation axis;

head mounting means for mounting said head member;

second driving means for driving said head mounting means to incline said rotation axis of said head member relative to a precession axis intersecting said rotation axis, and for moving said head member to inclined positions with said rotation axis precessed about said precession axis; and

third driving means for relatively moving said head mounting means across said holding surface.

2. A machine according to claim 1 wherein said first

driving means is arranged to drive surface of said working member in a lateral direction relative to said holding surface, and said second driving means is adapted to rotate said surface of said working member relative to a position on said holding surface so that a direction of lateral relative movement of said surface of said working member and said holding surface rotate relative to said position on said holding surface.

3. A machine according to claim 1 or claim 2, wherein said second driving means is arranged to move said head member to inclined positions distributed through an integer number of 360° of precession of said rotation axis about said precession axis.

4. A machine according to any preceding claims, wherein said second driving means is arranged to move said head member in precession steps.

5. A machine according to claim 4, wherein said second driving means is arranged to move said head member in precession steps which are symmetrically distributed about the precession axis through an integer number of 360° of angle of precession about the precession axis.

6. A machine according to any one of claims 1 to 4, wherein said second driving means is arranged to incrementally carry out the precession at precession steps which are not an integer division of 360°.

7. A machine according to any preceding claim wherein said head mounting means is arranged such that said precession axis intersects said rotation axis at or near said abrasive member.

8. A machine according to any preceding claims, including control means for controlling said first and second driving means such that the rate of movement of said head member about said rotation axis is substantially smaller than the rate of rotation of said head member.

9. A machine according to any preceding claim, wherein said head mounting means includes first and second arcuate members arranged orthogonally, each with a centre of curvature arranged to lie on an axis passing through or near said working member, said head member being mounted at a second end thereof to said first and second arcuate members by said second driving means to move said

second end of said head member in a respective orthogonal arc about a respective axis of the arcuate members.

10. A machine according to any preceding claim, wherein said third driving means is arranged to also relatively move said head member to and away from said holding surface.

11. A machine according to any preceding claim, wherein said holding surface is arranged to be relatively rotated with respect to said head mounting means.

12. A machine according to any preceding claim, wherein said working member is bulbous.

13. A machine according to claim 12, wherein said working member is compliant.

14. A machine according to any preceding claim, including control means operative to receive information on the topography of said workpiece and to control said second driving means to precess said head member about said precession axis normal to the surface of said workpiece at a position being abraded or polished.

15. A machine according to claim 14, wherein said control means is operative to receive information on the roughness of said workpiece and a rate of removal for material removed from said workpiece by said working member, to control said third driving means to move said head mounting means in a repeated figuring pattern and to control said first, second and third driving means to remove less than four times a local roughness average for a region of the workpiece being polished or abraded during each configuring pattern.

16. A machine according to claim 15, wherein said control means is adapted to control said second driving means to use varied inclined positions about said precession axis for each figuring pattern.

17. A method of abrading or polishing the surface of a workpiece, the method comprising:

mounting the workpiece on a holder;

relatively inclining a head member arranged along a rotation axis and having a working member arranged axially on said rotation axis and on said head member with a surface for abrading or polishing the surface of said workpiece, so that said rotation axis is inclined relative to a precession axis intersecting said rotation

axis, said precession axis being normal to the surface of said workpiece at an area of contact of said surface of said working member;

rotation said head member about said rotation axis;

contacting said surface of said working member to said surface of said workpiece so that said surface of said working member moves in a direction laterally across said surface of said workpiece;

moving the inclined head member to inclined positions rotated about said precession axis; and

moving the incline head member to relatively move said working member and said surface of said workpiece in a figuring pattern.

18. A method according to claim 17, wherein the step of moving the inclined head member to inclined positions rotated about said precession axis maintains an angle at which said head member is inclined relative to said precession axis substantially constant.

19. A method according to claim 17 or claim 18, wherein said inclined head member is moved in said figuring pattern for each of a plurality of inclined positions rotated about said precession axis.

20. A method according to any one of claims 17 to 19, wherein said inclined positions rotated about said precession axis are distributed through an integer number of rotations around said precession axis.

21. A method according to any preceding claim, wherein said head member is moved in steps to said inclined positions rotated about said precession axis.

22. A method according to claim 21, wherein said inclined positions are symmetrically distributed about said precession axis around an integer number of rotations about said precession axis.

23. A method according to claim 21, wherein said inclined positions are not an integer division of 360° of rotation about said precession axis.

24. A method according to any one of claims 17 to 23, wherein said precession axis intersects said rotation axis at or near said working member.

25. A method according to any one of claims 17 to 24, wherein the rate of movement of said head member about

said precession axis is substantially smaller than the rate of rotation of said head member.

26. A method according to any one of claims 17 to 25, wherein said workpiece is relatively rotated with respect to said head member.

27. A method according to any one of claims 17 to 26, wherein said working member is bulbous.

28. A method according to claim 27, wherein said working member is compliant and the position of said working member relative to said surface of said workpiece is controlled to control the area of contact between said surface of said workpiece and said working member.

29. A method according to any one of claims 17 to 28, wherein the movement of said head member is controlled in dependence upon information on the topology of said workpiece.

30. A method according to claim 29, including receiving information on the roughness of said workpiece and a rate of removal for material removed from said workpiece by said working member, controlling the movement of said

head member to move in a repeated figuring pattern, and controlling the removal of material to remove less than four times a local roughness average for a region of the workpiece being polished or abraded during each figuring pattern.

31. A method according to claim 30, wherein varied precession rotations of said head member are used for each figuring pattern.

32. A machine for abrading and/or polishing a workpiece, the machine comprising:

a holding surface for holding said workpiece;

a head carrying a face for abrading and/or polishing said workpiece;

a mechanical arrangement for supporting and moving said head across, to and from said holding surface;

a tilting mechanism mounted on said mechanical arrangement and arranged to tilt said head about a pivot to an angle relative to said holding surface; and

control means for controlling the position and tilt of said face of said head by controlling said mechanical arrangement and said tilting mechanism, said control means being operative to compensate for the movement of

said face when tilted by controlling said mechanical arrangement.

33. A machine according to claim 32, wherein said control means is operative to perform the compensating control by calculating the change in position of said face caused by the tilt.

34. A machine according to claim 32, wherein said control means is operative to perform the compensating control by looking-up the change in position of said face caused by the tilt.

35. A method of abrading or polishing a workpiece, the method comprising:

mounting the workpiece on a holder;

moving a head using a mechanical arrangement having a face for abrading or polishing said workpiece in a figuring pattern;

during the figuring, tilting said head about a pivot to an angle relative to said workpiece; and

controlling the position of said head in dependence upon the degree of tilt of said head so as to compensate for movement of said face relative to said workpiece caused by tilting said head.

36. A method according to claim 35, wherein the movement of said face relative to said workpiece caused by tilting said head is calculated and used to control said mechanical arrangement.

37. A method according to claim 35, wherein the movement of said face relative to said workpiece caused by tilting said head is looked-up using the angle of tilt and used to control said mechanical arrangement.

38. A carrier medium storing instructions for controlling a processor to control a machine according to any one of claims 1 to 16 or 32 to 34.

39. A tool for abrading or polishing a workpiece, the tool comprising:

a bulbous compliant member;

a holder holding said compliant member so that the compliant member bulges there out of;

a membrane arranged over a surface of said compliant member to provide a working surface for abrading or polishing said workpiece;

said membrane being flexible to follow the compliance of said compliant member; and

a membrane carrier carrying said membrane and releasably attached to said holder to allow said membrane and said membrane carrier to be removed from said holder.

40. A tool according to claim 39, wherein said membrane carrier is mechanically clamped to said holder.

41. A tool according to claim 39 or claim 40, wherein said holder comprises a substantially cylindrical member, said compliant member is held at one end of the cylindrical member and said membrane carrier comprises a substantially cylindrical sleeve fitted over said cylindrical member.

42. A tool according to claim 41, wherein said cylindrical member has an outer surface which tapers away from said compliant member and to which said cylindrical sleeve is clamped, and said cylindrical sleeve is shaped to deform to the taper of the outer surface of said cylindrical member.

43. A tool according to any one of claims 39 to 42, including means to allow said membrane and said surface of said compliant member to mov relatively laterally.

44. A tool according to claim 43, wherein said means comprises a lubricant or an unset adhesive.

45. A tool according to any one of claims 39 to 44, wherein said membrane has an abrasive material bonded thereto or impregnated therein.

46. A tool according to claim 45, wherein said membrane is formed of a matrix material and a reinforcing material embedded in said matrix material.

47. A tool according to claim 45 or claim 46, wherein said abrasive material is bonded to said membrane in discrete areas over said membrane.

48. A tool according to any one of claims 45 to 47, wherein said abrasive material is bonded to said membrane by epoxy or nickel.

49. A tool according to any one of claims 45 to 47, wherein said abrasive material is bound together and bonded to said membrane using a binder material containing an erosion promoter material to promote the erosion of the binder material during abrading or polishing to expose fresh abrasive material.

50. A tool according to any one of claims 45 to 49, wherein said abrasive material is bound together and bonded to said membrane using a binder material containing a lubricant material.

51. A tool according to any one of claims 39 to 50, wherein said compliant member comprises a volume of fluid and a flexible membrane covering at least in part said volume of fluid, and said volume of fluid is contained by said holder and said flexible membrane in combination and said flexible membrane is sealed to said holder.

52. A tool according to any one of claims 39 to 44, wherein said membrane comprises an adsorbant material for adsorbing abrasive material applied thereto for abrading or polishing said workpiece.

53. A tool according to claim 52, wherein said membrane is formed of a cloth material.

54. An abrasive cup for fitment to a tool for abrading or polishing a workpiece, the abrasive cup comprising:

a sheet of flexible material having a shape for fitment to a corresponding bulbous compliant member of

said tool, said sheet being sufficiently flexible to flex during abrading; and

a carrier carrying said sheet around a periphery of said sheet, said carrier having an arrangement for releasably fixing said abrasive cup to said tool.

55. An abrasive cup according to claim 54, wherein said arrangement comprises a mechanical clamping arrangement.

56. An abrasive cup according to claim 54 or claim 55, wherein said carrier comprises a sleeve for fitment to said tool, wherein said sheet is mounted at one end of said sleeve.

57. An abrasive cup according to claim 56, wherein said sleeve is shaped to be radially deformable at a second end thereof.

58. An abrasive cup according to any one of claims 54 to 57, wherein said sheet has an abrasive material bonded thereto or impregnated therein for abrading or polishing said workpiece.

59. An abrasive cup according to claim 58, wherein said sheet comprises a matrix material and a reinforcing material embedded in said matrix material.

60. An abrasive cup according to claim 58 or claim 59, wherein said abrasive material is bonded to said sheet in discrete areas over said sheet.

61. An abrasive cup according to any one of claims 58 to 60, wherein said abrasive material is bonded to said sheet by epoxy or nickel.

62. An abrasive cup according to any one of claims 58 to 61, wherein said abrasive material is bound together and bonded to said sheet using a binder material containing an erosion promoter to promote the erosion of the binder material during abrading or polishing to expose fresh abrasive material.

63. An abrasive cup according to any one of claims 58 to 62, wherein said abrasive material is bound together and bonded to said sheet using a binder material containing a lubricant material.

64. An abrasive cup according to any one of claims 54 to 57, wherein said sheet comprises an adsorbant material for adsorbing abrasive material applied thereto for abrading or polishing said workpiece.

65. An abrasive cup according to claim 64, wherein said sheet is formed of a cloth material.

66. A method of forming an abrasive cup according to any one of claims 54 to 65, the method comprising:

forming said sheet of material over a carrier into a bulbous shape for fitment to a bulbous compliant member of said tool; and

fixing said sheet to said carrier at a periphery of said sheet.

67. The method of claim 66, wherein said forming step comprises applying said sheet to a forming tool, and forming said sheet to said bulbous shape.

68. The method of claim 67, including a final step of pressing and/or heating said sheet.

69. The method of any one of claims 66 to 68, wherein said sheet comprises a substrate material and the method

includes applying a flexible sheet on said substrate material for abrading or polishing said workpiece.

70. A machine for abrading or polishing a workpiece, the machine comprising:

a body extending along a rotation axis and having pressure transmission means at one end of said body, said body being rotatable about said rotation axis;

a head releasably mounted on said end of said body, said head comprising a head housing, a head fluid pressure transmission means, and a resilient membrane forming a sealed head fluid chamber filled with fluid, said head fluid pressure transmission means being arranged in said head housing to cooperate with said pressure transmission means to transmit pressure to said head fluid chamber, and said resilient membrane being held at a periphery thereof by said head housing to extend bulbously therefrom for the application of pressure to said workpiece during abrading or polishing.

71. A machine according to claim 70, wherein said body has a body fluid chamber filled with fluid terminating at said pressure transmission means.

72. A machine according to claim 71, wherein said body fluid pressure transmission means and said head fluid pressure transmission means comprise respective displacement devices mounted respectively in said body and said head and coupled to one another when said head is mounted to said body.

73. A machine according to claim 71 or claim 72, wherein said body fluid chamber and said head fluid chamber are filled with incompressible fluid.

74. A machine according to any one of claims 71 to 73, including fluid pressure control means comprising a passage from said body fluid chamber, to a fluid pressure control arrangement provided separate to said rotatable body.

75. A machine according to any one of claims 70 to 74, wherein said head is axially mountable to said body.

76. A tool head for releasably mounting on a tool body of a machine for abrading or polishing a workpiece, the tool body having pressure transmission means, the tool head comprising:

a head housing, a head fluid pressure transmission means and a resilient membrane forming a sealed head fluid chamber for holding fluid, said head fluid pressure transmission means being arranged in said head housing to allow the coupling of fluid pressure in said head fluid chamber to said pressure transmission means, and said resilient membrane being held at a periphery thereof by said head housing to extend bulbously therefrom for the application of pressure to said workpiece during abrading or polishing.

77. A tool head according to claim 76, wherein said head fluid transmission means comprises a displacement device for coupling with said pressure transmission means comprising a displacement device when said tool head is mounted on said tool body.

78. A tool head according to claim 76 or claim 77, wherein said head fluid chamber is filled with incompressible fluid.

79. A method of controlling polishing or abrading of a workpiece, the method comprising:

receiving data defining an influence function of a tool, the influence function defining the pattern of

removal of material from the workpiece for a predetermined dwell time or speed of said tool;

receiving data on a desired profile and a current profile of a surface of said workpiece;

determining the difference between the desired profile and the current profile to determine a target removal profile;

determining dwell times or tool speeds for predetermined positions on said surface of said workpiece to provide a predicted removal profile by performing a numerical optimisation of the dwell times or tool speeds for the predetermined positions using the influence function to reduce at least one cost function; and

controlling the polishing or abrading of said workpiece using the determined dwell times.

80. A method according to claim 79, wherein said numerical optimisation comprises determining a set of dwell times or tool speeds for the predetermined positions which have a minimum value for a difference between said target removal profile and said predicted removal profile.

81. A method according to claim 79, wherein said numerical optimisation comprises a genetic algorithm,

wherein values for the dwell times or tool speeds comprise a gene pool for the algorithm.

82. A method according to any one of claims 79 to 81, wherein said desired profile comprises a desired radial profile for a circular workpiece, said influence function is defined as a 2D function, and the predetermined positions comprise radial positions across said surface of said workpiece.

83. A method according to any one of claims 79 to 81, wherein said desired profile comprises a desired 3D profile, said influence function is defined as a 3D function, and the determined positions comprise a 2D array of positions across said surface of said workpiece.

84. A method according to any one of claims 79 to 83, wherein a said cost function for predetermined dwell times or tool speed is the sum of squares of the errors between the target removal profile and the predicted removal profile obtained using the predetermined dwell times.

85. A method according to any one of claims 79 to 84, wherein said numerical optimisation iteratively searches

for the best dwell times or tool speeds for said predetermined positions to substantially achieve the desired profile.

86. A method according to any one of claims 79 to 85, including measuring a profile of said workpiece after polishing, comparing the measured profile with said current profile before polishing to determine a measured removal profile, determining dwell times or tool speeds expected to achieve said measured removal profile using said numerical optimisation, determining at least one correction factor for dwell times or tool speeds using the dwell times or tool speeds used to polish said workpiece and the dwell times or tool speeds expected to achieve said measured removal profile, and applying said at least one correction factor to dwell times or tool speeds used in future polishing of said workpiece.

87. Apparatus for abrading or polishing a workpiece, the apparatus comprising:

first inputting means for inputting data defining an influence function of a tool, the influence function defining the pattern of removal of material from the workpiece for a predetermined dwell time or speed of said tool;

second inputting means for inputting data on a desired profile and a current profile of a surface of said workpiece;

first determining means for determining a target removal profile from the difference between the desired profile and the current profile;

second determining means for determining dwell times or tool speeds for predetermined positions on said surface of said workpiece to provide a predicted removal profile by performing a numerical optimisation of the dwell times or tool speeds for the predetermined positions using the influence function to reduce at least one cost function; and

control means for controlling the polishing or abrading of said workpiece using said tool and the determined dwell times or tool speeds.

88. Apparatus according to claim 87, wherein said second determining means is adapted to determine a set of dwell times or tool speeds which have a minimum value for a difference between said target removal profile and said predicted removal profile.

89. Apparatus according to claim 87, wherein said second determining means is adapted to carry out a genetic

algorithm, wherein values for the dwell times or tool speeds for the predetermined positions comprise a gene pool for the algorithm.

90. Apparatus according to any one of claims 87 to 89, wherein said second inputting means is adapted to input said desired profile as a desired radial profile for a circular workpiece, said first inputting means is adapted to input said influence function as a 2D function, and said second determining means is adapted to determine said dwell times or tool speeds for radial positions across said surface of said workpiece.

91. Apparatus according to any one of claims 87 to 89, wherein said second inputting means is adapted to input said desired profile as a 3D profile, said first inputting means is adapted to input said influence function as a 3D function, and said second determining means is adapted to determine said dwell times or tool speeds for a 2D array of positions across said surface of said workpiece.

92. Apparatus according to any one of claims 87 to 91, wherein said second determining means is adapted to determine said dwell times or tool speeds using a said

cost function for determined dwell times or tool speeds comprising the sum of the squares of the errors between the target removal profile and the predicted removal profile obtained using the determined dwell times or tool speeds.

93. Apparatus according to any one of claims 87 to 91, wherein said second determining means is adapted to perform said numerical optimisation iteratively to search for the best dwell times or tool speeds for said predetermined positions to substantially achieve the desired profile.

94. Apparatus according to any one of claims 87 to 93, including measuring means for measuring a profile of said workpiece after polishing, comparing means for comparing the measured profile with said current profile before polishing to determine a measured removal profile, third determining means for determining dwell times or tool speeds expected to achieve said measured removal profile, fourth determining means for determining at least one correction factor for dwell times or tool speeds using the dwell time or tool speeds expected to achieve said measured removal profile and the dwell times or tool speeds used to polish said workpiece, and correction

means for applying said at least one correction factor to dwell times or tool speeds used in future polishing of said workpiece.

95. A computer program for controlling a computer to carry out the method of any one of claims 79 to 86.

96. A carrier medium carrying the computer program according to claim 95.

97. A method of manufacturing a device comprising the method of any one of claims 17 to 26, 35 to 37 or 79 to 86.